Chapter 4
Land Management Systems at the Interface Between Forestry and Agriculture

Gerald Kapp and David Butler Manning

Abstract Trees cultivated on agricultural land are playing an ever more significant role in rural development while at the same time also providing a range of ecosystem services such as soil protection, biodiversity conservation and greater carbon sequestration. All over the world, at the interface between forestry and agriculture, a wide variety of agroforestry systems are being implemented as a means to provide much needed wood of different dimensions and qualities, other non-timber forest products as well as animal and agricultural crop produce. An overview of some of the main agroforestry approaches making a contribution to rural development globally are presented, including innovative examples of modern agroforestry. Subsequently, another land use system flanking forestry and agriculture that has been growing in importance internationally in recent years is presented, namely short rotation coppice management. Distinct from traditional agroforestry systems in that in most cases wood is the only production goal, short rotation coppice plantations are a highly productive form of agricultural land use providing farmers with a great deal of flexibility, potentially high yields and certain ecosystem services.

Keywords Agroforestry systems • Short rotation coppice • Farm forestry systems • Non-timber forest products

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4.1 Introduction

In this chapter tree-based land use systems implemented by farmers and agricultural enterprises are presented from the managerial perspective. It includes a brief overview of the different agroforestry and farm forestry systems backed up by some case studies. The principal focus, however, is on short rotation coppice; an innovative tree-based form of agriculture that has steadily grown in importance over recent years. In contrast to the traditional agroforestry systems, short rotation coppice is often geared solely towards the production of wood – for either energetic or material use. In most cases no other crops or livestock are integrated within the land use system, although incorporation within agroforestry systems is also possible. The physical, labour and financial characteristics, conflicts and interactions of tree-based subsystems within the farm economy are assessed.

In most industrialised countries wood production and agriculture are neatly separated between departments in public administrations and in land use systems on the ground. There are some overarching reasons for this. Modern agriculture generally produces much higher benefits per hectare and year, but it needs fertile sites, predominantly on flat land easily accessible to machines. Over time this has led to the situation that forests are principally confined to mountains, less fertile, dry or wet areas. Yet a glance at many landscapes reveals that trees are not confined to forests and that in fact the agricultural-pastoral landscapes contain quite a lot of trees, scattered in little groves, lines, hedges or plantations, and that in many, often degraded forests, livestock grazes and browses and shifting agriculture is still practised.

Due to the fact that in many temperate countries agroforestry systems were more abundant in the past, some people tend to conclude that agroforestry is an outdated remnant of the past. This is certainly not the case. Spread all over the world, agroforestry systems are constantly adapted to the prevailing demands and the framework conditions of changing societies.

Advances in agroforestry can play a significant part in the achievement of virtually all of the UN's millennium development goals (Garrity 2004a). The means by which agroforestry can contribute to rural development according to the World Agroforestry Centre (ICRAF) are by helping to provide food, generating income and building assets, advancing health and nutrition, conserving biodiversity, protecting watershed services and assisting adaptation to climate change. A continued expansion of agroforestry land use systems globally, and also of short rotation coppice management, will bring with it substantial benefits in terms of the local environment, in turn producing benefits relating to energy security, agriculture, a revival of biodiversity and also greater employment. The role of trees cultivated on agricultural land as a means to mitigate greenhouse gas emissions is also of considerable importance and has been widely underestimated to date (Pachauri 2012). This maintenance of high carbon stocks in terrestrial ecosystems and agri-ecosystems is vital to reducing emissions in both developing and developed countries (Minang et al. 2012).

Smallholder timber production is already an important source of wood in many countries, especially where the forest cover is low. In Kenya, for example, two thirds of the country's woody biomass stems from non-forest areas (Holmgren et al. 1994) and it is estimated that in Bangladesh 90 % of the wood used is produced on agricultural land. In India the figure is approximately 50 % (Garrity 2004b). These values underline the importance of trees in agriculture and support the recent assertion by Minang et al. (2012) that, "tree-based and managed agroforestry systems are beginning to emerge at some scale."

4.2 Some Definitions

4.2.1 Types of Agroforestry and Farm Forestry Systems

Throughout the world a large variety of 'tree'-related systems can be found with a direct connection to agriculture. They are either integrated into the arable or pastoral landscape, where border effects are predominant and no 'forest climate' is present, or they are farm forests with direct links (e.g., labour, finance, use of farm equipment, wood, local climate) to the farm economy. Agroforestry generally includes all land use systems where woody perennials fulfil agricultural as well as forestry functions. More explicitly, agroforestry can be defined as a land use where agricultural crops and/or animals are managed together with woody perennials on the same plot, simultaneously or in succession, to profit from this combination. Farm forestry involves a different focus on land use systems, with forest trees managed within a farmstead. The following figure (Fig. 4.1) provides an overview of common agro- and farm forestry systems found in temperate and tropical countries. It should be noted that 'trees' are often understood in the sense of woody perennials, that is, including shrubs, palms and bamboos. The various systems each usually have quite distinct physical appearances, growth characteristics, management requirements and financial returns. Nevertheless, a limited overlapping of the systems may occur.

A similar, but slightly different approach is taken by the FAO with its concept of 'trees outside forests,' which refers to "trees on land not defined as forest and other wooded land" (thus excluding farm forests). It embraces trees and shrubs on agricultural land, barren land and built-on areas, including agroforestry systems, orchards, small clumps of trees, permanent meadows and pastures, trees growing on farms and in urban and per urban zones, in lines along rivers, canals and roads, and in gardens, parks and towns (see Bellefontaine et al. 2002, presenting many case studies from around the world).

As many traditional agroforestry systems are well documented (e.g., Nair 1993; Huxley 1999; Bellefontaine et al. 2002; Guuroh et al. 2012) the focus of this chapter is on selected examples of general interest, highlighting recent and innovative

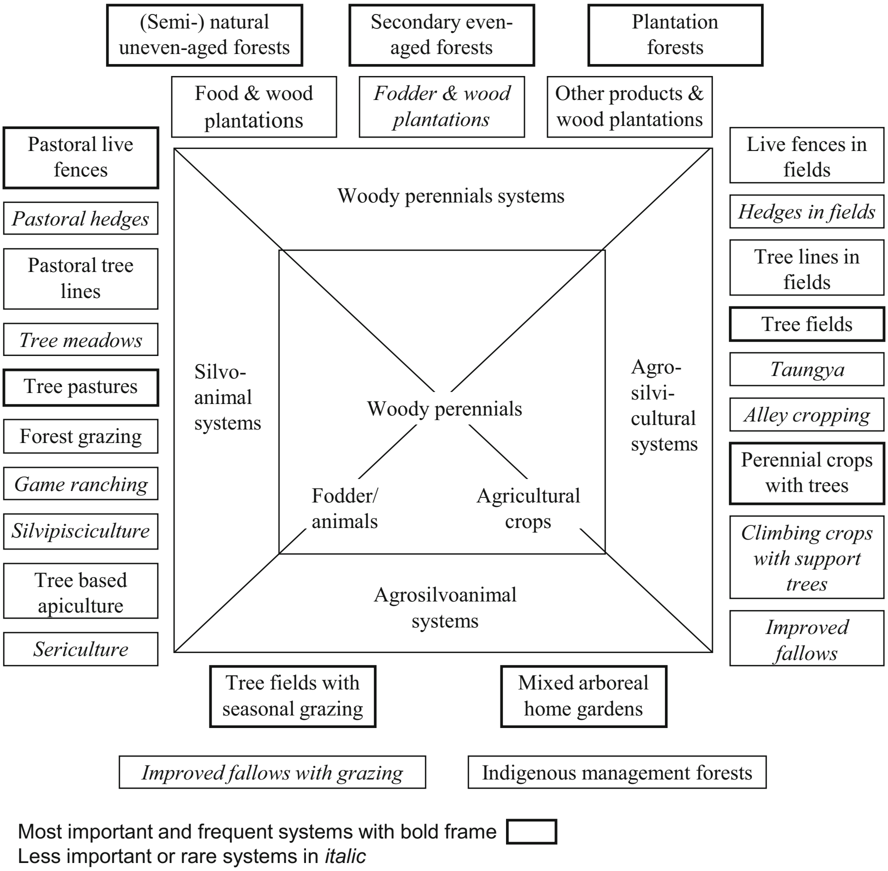

Fig. 4.1 Overview of agroforestry and farm forestry systems in temperate and tropical zones (Source: Kapp (1998), modified)
The term *silvoarable systems* is used synonymously with *agrosilvicultural systems*. All pasture related *silvoanimal systems* are also described as *silvopastoral systems*

systems. Their strengths and weaknesses, and the corresponding opportunities and threats are summarised in SWOT analyses.

4.2.2 Short Rotation Coppice

A short rotation coppice is a plantation of fast growing trees or shrubs, the primary objective of which is to produce high yields of wood over short periods of time. Confusingly, short rotation coppice (sometimes abbreviated as SRC) is one of a number of terms frequently used interchangeably in the literature although in many cases the terms are not synonymous. Various studies refer to short rotation coppice as short rotation crops (also inconveniently abbreviated as SRC), short rotation woody crops, short rotation forestry, arable coppice, short rotation intensive culture, etc. The term short rotation coppice is preferred here for its specificity: coppicing is central to the management system and relates specifically to woody species. Short rotation forestry, for example, does not necessarily involve coppicing and short rotation crops need not necessarily incorporate either coppicing or even woody species.

As part of the management system, the trees are cut back to just above ground level at the end of the first – and after each subsequent – rotation, with the following generations based on sprouts emerging from the stools remaining in the ground (i.e., coppicing). The system is particularly flexible in that plantations may be established in conventional blocks of differing sizes and with widely diverging stocking densities, or they may be established in strips resembling hedgerows or windbreaks. The differing rotation lengths are another source of flexibility. Short rotation coppice plantations are usually harvested in 2–5 year rotations, but may also have longer rotations of between 10 and 20 years, depending on the production goals, the market situation, labour capacities, etc. Plantations established to produce fibres for material use in the pulp and paper industry, for instance, will have longer rotations and lower stocking densities than plantations established to produce wood chips or billets to be used as woodfuel. Generally the second and later generations of trees will not produce wood suitable for use in fibre production. Once established, a plantation can be harvested for 25 years or more, depending on the species and site, before the vitality of the stools begins to decline and a renewal of the plantation is required.

The annual biomass yield attained in short rotation coppice plantations depends on the tree species and growth conditions, and varies between roughly 7–18 t dry bulk (bdt) per hectare and year when grown on suitable sites in temperate regions, and 15–30 bdt/ha/a in the tropics. Although most fast growing tree species are generally less site demanding than traditional bioenergy crops, even these have certain site requirements, which, if they are not met, will result in very low yields or even complete crop failures. The net biomass productivity of short rotation coppice is considerably higher than in natural and in sustainably managed high forests (e.g., Bemmann et al. 2011). In many cases it achieves levels of productivity comparable to traditional agricultural production. It is not only the high levels of productivity that make short rotation coppice attractive, it is also the potential benefits in terms of counteracting damage to watersheds, wind and water erosion, pollution and as a means to enhance biodiversity relative to annual crops (e.g., Blick et al. 2003; Burger 2006; Kroiher et al. 2008).

The establishment of short rotation coppice plantations resembles a land use hybrid nestled somewhere between agriculture, horticulture and forestry. In certain countries there is a strict legal separation between land used for agriculture and land that is designated forest land. Contrasting rights and obligations are associated with each land classification, as well as different opportunities for income generation, and different values are placed on the two land types as a consequence. Arable land allows landowners the greatest freedom to make decisions on crops, to adapt to market conditions in the short term and so to avail of the greatest income generation opportunities. In these countries, therefore, it is important that the agricultural status of the land is maintained when trees are planted for short rotation coppice management. In many countries short rotation coppice is now recognised as an agricultural form of land use rather than as forestry.

4.3 Evolution of Land Uses and Lines of Thought

4.3.1 Shifting Cultivation and Farm Forestry in the Tropics

In the past, and still to this day in many places, farmers established their property in areas of natural forest by clearing trees using both tools and fire so that they could either plant their crops or establish pastures. Often other parts of the property remained under forest. This remnant area of *(semi-)natural uneven-aged forest* has in many cases been exploited. The most valuable trees have usually been harvested by timber companies or local individuals, and the logs or boards sold on to timber merchants. These remnant forests are located further away from the farm house or on land less suitable for tillage or pastoral use due to their steepness, the soil properties or the water regime. At the agricultural frontier in developing countries, farm property sizes are still relatively large, often in the range of 10–100 ha. Due to limitations in terms of family labour force, most farmers cannot clear and manage all of this land in the beginning. However, in many countries unmanaged natural forest land is subject to an unclear property status. Often the clearing and the non-intensive use of the land, for example, with grazing of less than one animal per hectare, is accepted as a demonstration of land ownership.

Such remnant forests are also a continuous source of new fertile land; areas cleared and burnt to provide a substrate to replace other plots where crop growth has decreased as a consequence of weed invasion, soil erosion, compaction or nutrient depletion, if no special techniques and fertilisers are available. This frequently leads to a shifting cultivation cycle as depicted in Fig. 4.2.

This process of temporarily, and sometimes permanently, abandoning tillage or pasture leads to the establishment of *secondary, even-aged forests*. For the first 5–10 years these stands can barely be used, except occasionally for some non-timber forest products. Exploitation usually restarts once individuals of timber tree species within the secondary forest have grown to harvestable dimensions.

Farm forests are a constant source of timber for fencing and housing, of wild fruit, game, medicine, materials for handcrafts and roofing, and preserve ground water and springs. Beyond these material uses, farm forests sometimes also have cultural benefits, as landscape attractions, the sites of graveyards and as places of spiritual value. These less tangible benefits often ensure the continued existence of remnant forests.

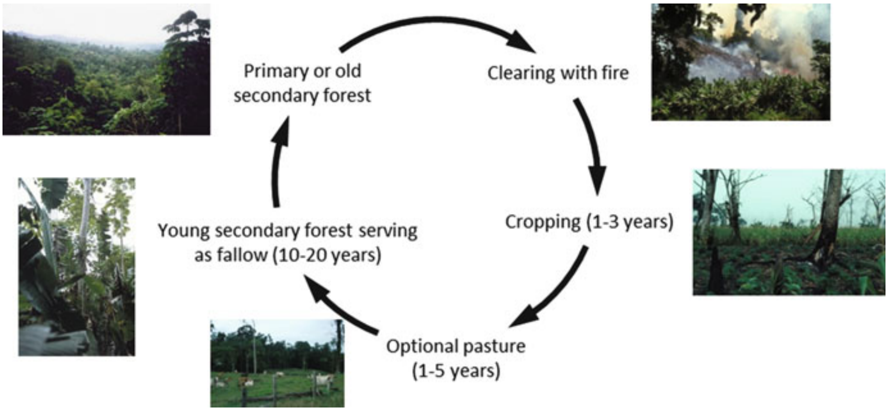
Primary or old secondary forest
Clearing with fire
Cropping (1-3 years)
Optional pasture (1-5 years)
Young secondary forest serving as fallow (10-20 years)

Fig. 4.2 A typical shifting cultivation cycle, a type of sequential agroforestry system. This cycle may or may not include a pasture phase

In addition to (semi-)natural and secondary forests there is a third forest type. Many farmers experiment with the growing of commercial, frequently also exotic timber trees in *plantation forests*. Such plantations are usually small in size.

The frequency and size of forests situated on farms in two neighbouring areas of Costa Rica and Panama were analysed as part of a comprehensive field study (Table 4.1). At the time of study the areas had been colonised 10–30 years.

The results of the survey indicated that in both regions about half of the farms still had substantial forest land that was in acute danger of being gradually converted to agriculture. Equally, the local farmers also recognised that 30–59 % of their forest areas were not suitable for agricultural use. More than half of the farmers in both regions had young secondary forest serving at that time as forest fallow and about 10 % had established plantation forests. These findings are still characteristic of many parts of the developing world.

In view of the important functions of (semi-)natural farm forests as a means to complement livelihoods from farming, for soil conservation, the protection of biodiversity and in terms of carbon sequestration, it is vital that farmers be provided with technical and political incentives to engage in appropriate management of such forests (Kapp 1996).

Some technical and financial information on the feasibility of the management of (semi-)natural farm forest is shown in the following summary of a case study from Panama. The case study highlights that although farm forest management may be less attractive economically in the short term, in the long term it is more feasible than uncontrolled exploitation, both ecologically and economically (Box 4.1).

Similar polycyclic silvicultural models are applied in many countries; for example, in Venezuela (Plonczak 1989) and in a large private enterprise in Paraguay (Sociedad Agrícola Golondrina et al. 2004), as well as in Africa and Southeast Asia.

The main features of *(semi-)natural, uneven-aged forest management* are presented in the form of a SWOT analysis in Table 4.2.

Table 4.1 The use of forest land and land use planning on farms in two neighbouring regions in Costa Rica and Panama

Object	Unit	Talamanca, Costa Rica	Changuinola, Panama
Area surveyed	km^2	600	1,500
Number of smallholders visited and surveyed	–	197	271
Average farm size			
of all farms	ha	20	28
of farms with forests only	ha	33	39
Proportion of farms with forest plantations	%	12	9
Size of forest plantation	ha	3	8
Proportion of farms with forest fallows	%	52	57
Size of forest fallow	ha	5	8
Proportion of farms with (semi-)natural forest	%	40	47
Size of (semi-)natural forest	ha	11	12
Proportion of farms where forest products are used	%	53	57
Proportion of farms that will keep at least part of their forest	%	48	35
Proportion of forest area the farmer deems suitable for pastoral use	%	43	70
Proportion of forest area the farmer deems suitable for cropping	%	41	53

Source: Kapp et al. (1991)

Table 4.2 SWOT analysis of on-farm (semi-)natural, uneven-aged forest management

Strengths	Risk is spread as a consequence of the diversification of farm production
	Higher labour productivity than agriculture
	Environmental co-benefits
	Use of land unsuitable for agriculture
Weaknesses	Lack of silvicultural knowledge
	Market access often problematic, difficult to aggregate sufficiently high timber volumes
	Lower land productivity than agriculture
Opportunities	Additional income from payments for environmental services (PES), carbon credits
	Land titling with forest management plan
	Increasing demand in many countries for wood for construction, paper and energy
Threats	Large proportions of non-commercial tree species
	Restrictive forest laws

Box 4.1 Technical and Financial Feasibility of (Semi-)Natural Farm Forest Management: A Case Study from Panama

The 40 ha making up the moistest area of the Sánchez’ 71 ha farm was still covered by natural forest, which had been partly exploited. Some 29 ha of the

(continued)

Box 4.1 (continued)

area provided grazing for 21 cattle. Cocoa and maize were each planted on 1 ha. Traditionally, the farmer dedicated 120 working days to timber exploitation, yielding US $3,810/year, 50 days to cattle management yielding US $600/year, 50 days to the cocoa crop and 17 days to the maize, yielding US $60 and US $150, respectively. The extractive exploitation of the forest led to degradation. The main commercial species were *Carapa guianensis, Pentaclethra macroloba* and *Pterocarpus officinalis*, which contributed 104 m^3/ha to the total standing harvestable stock of 129 m^3/ha. The most abundant species was the palm *Raphia taedigera*, accounting for 45 % of the overall stocking density of 428 trees/ha.

The core of the newly executed on-farm forest management plan, which was introduced in cooperation with a research project coordinated by CATIE (Turrialba, Costa Rica), was a polycyclic silvicultural system oriented towards final crop trees with a timber harvesting cycle of 20 years. With yearly cuttings on 1.55 ha, only 27 % of the 21 m^2 tree basal area is removed, corresponding to a timber volume of 97 m^3 (= 62 m^3/ha). Prior to cutting, 100 potential final crop trees/ha are selected, marked and, where necessary, liberated, with the latter operation to be repeated after 10 years. These potential final crop trees constitute the collective of commercially valuable but still young trees to be cut in future harvest cycles; that is, in 20 or 40 years. Immediately after cutting, the logs are sawed into boards by the farmer using a chainsaw. To transport the sawn timber out of the forest, the farmer installed a cable logging system, an adapted version of the cable system employed by a neighbouring banana company. The gross income from this new system is in the range of US $2,015/year, which is 6 % less than the traditional destructive exploitation system. This provides the farmer with an income of US $38/working day, which is attractive compared to the average local wage of US $8/working day. Forest stocks will be improved under this new form of management, and after 20 years yields are expected to rise to 126 % of the traditional exploitation system, which, had it continued, would have left a degraded forest or cleared land.

Source: Kapp (1998)

4.3.2 Recent Developments in Agroforestry Systems in Tropical and Temperate Zones

Agroforestry systems are most prominent in tropical and developing countries, where they have a decisive role in providing the rural and to a lesser degree the urban population with food, fuelwood, timber and other products. There are studies from many countries demonstrating that over half of the total wood supply comes from such trees outside the forest (Bellefontaine et al. 2002).

Agroforestry systems are of increasing importance for a sustained agricultural production in the context of adaptation to climate change. They play a prominent role in ‘climate smart agriculture’ (The World Bank 2011), which is defined as an agriculture that, “sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation) while enhancing the achievement of national food security and development goals” (FAO 2012). Trees are also increasingly being integrated into ‘conservation agriculture’ and form a substantial pillar of ‘sustainable land management’ (SLM) technologies (Liniger et al. 2011). Trees can have exceptional effects, such as those of *Faidherbia albida*, prominent in large parts of semi-humid and semi-dry Africa. Researchers from GART in Zambia stated that crop yields under the canopy are around 30 % higher (The World Bank Institute, TerrAfrica 2012). This is due to its reversed leaf cycle, nitrogen fixing, deep rooting and nutritious pods, which are also appreciated by livestock.

Agroforestry hedge systems (‘alley cropping’), regularly pruned and providing materials for use as mulch or fodder, can successfully stop erosion and increase soil fertility and farm income on sloping lands, as demonstrated in the Sri Lankan–German Upper Mahaweli Watershed Management Project (GTZ 1998) incorporating a variation of this system in conjunction with their sloping agricultural land technology (SALT).

Another prominent agroforestry system throughout the tropics is mixed arboreal home gardens. In a recent study in the Bieha department of Burkina Faso (Guuroh et al. 2012) all of the 80 households surveyed managed home gardens composed of trees (25 species were found), crops and animals. Including their animal component, they contributed 60 % of the farm income.

The most prominent agroforestry research institution, the World Agroforestry Centre (ICRAF), stated that, “it is possible to have higher yields, more carbon in the soil and biomass and greater resilience to droughts and temperature stress if trees are integrated into agricultural production landscapes through locally appropriate forms of agroforestry that modify local climate” (World Agroforestry Centre 2011). Constraints to agroforestry are mainly seen in misperceptions concerning the interactions between trees and crops, and in traditional agricultural policies that often ignore trees on farms and do not provide the necessary incentives.

In recent years agroforestry systems have been undergoing a revival in temperate zones as well, with potentially interesting implications for tropical agroforestry. Whereas forest pastures have largely vanished in temperate Europe, a modified form of tree pasture is a prominent modern land use system in New Zealand (Gordon and Newman 1997). In central Europe, hedgerows have gained new importance as aesthetic landscape elements and as ecologically valuable biotopes with a connective function (Reif and Schmutz 2001), as shelters for year-round pasture for robust sheep and cattle races and as sources of bioenergy.

Another form of modern agroforestry re-emerging in central Europe is the planting of tree species producing valuable timber in single rows in fields and pastures (Bender et al. 2009; Dupraz and Liagre 2008). Only in recent years have such modern forms of agroforestry been promoted by European research projects

Table 4.3 SWOT analysis of on-farm agroforestry systems

Strengths	Risk is spread as a result of the diversification of farm production
	Better use of the space above and below ground leading to increased overall production and higher growth rates of freestanding trees
	Improved protection of agricultural soils against erosion
	Increased soil fertility (nutrient cycles, organic matter, less fertiliser needed)
	Investment and saving functions of valuable timber trees
	Environmental co-benefits
	Sustainable use of lower quality sites for agricultural production
Weaknesses	Competition of trees with crops for space, light, water and nutrients leading to reduced crop yields
	Impediment to mechanisation of plant production
	Management more complex and difficult
Opportunities	Availability of better tree cultivars with improved properties in terms of bole form, growth rates, branch diameters
	Better legal and administrative support for agroforestry land use systems
	Increasing demand in many countries for wood for construction, pulp and paper, and energy
Threats	Insufficient support from agricultural extension services
	Impeding laws and regulations

(e.g., Dupraz et al. 2005; Reeg et al. 2009) and agroforestry associations (e.g., Association Française d'Agroforesterie, www.agroforesterie.fr and EURAF - European Agroforestry Federation, http://euraf.isa.utl.pt/). The basic idea is to achieve higher benefits from the farm production area by integrating a small number (e.g., 20–30) of moderately fast growing valuable tree species (e.g., *Acer pseudoplatanus*, *Juglans spp*., *Fraxinus excelsior*, *Prunus avium*) that produce highly sought after wood. Under essentially free growing conditions, and with repeated pruning, marketable stem diameters of 40–60 cm can be reached in 30–70 years. The intermedia nut hybrid of *Juglans regia x Juglans nigra*, for example, exhibits very satisfactory growth rates and second generation nut hybrids (*Juglans x intermedia x Juglans mandshurica*) have reached an average stem diameter of 29 cm and an average tree height of 27 m in only 18 years (Mettendorf 2008).

Investments in the on-farm production of hybrid nut can yield an internal rate of return on capital of up to 10 % (Kapp 2009). Out-grower schemes could expect similar returns on investment.

Useful fruit, fodder and wood-producing trees (e.g., *Acer* sp., *Castanea crenata*, *Evodia dainellii*, *Juglans sinensis*, *Robinia pseudoaccacia*) have been planted in contour lines as a means to check erosion in many countries, such as in the case of the North Korean Restoration of Sloping Lands Project. These woody structures also represent good economic prospects (Kapp 2010) and could be adapted in other developing, including tropical countries.

These and other experiences clearly show that agroforestry systems have positive effects but also trade-offs with respect to physiology, labour and cash flow. To be successful, it is essential that these systems be specifically designed to suit the site so that the positive effects are optimised and the potentially negative effects kept to a minimum (Table 4.3).

4.4 Short Rotation Coppice in Industrialised and Developing Countries

In parts of the world where the supply of wood that may be obtained from forests by means of sustainable forest management is abundant, the scope for the establishment of short rotation coppice is limited. However, where the wood supply is short and insufficient to meet existing energy needs, or where the greater use of wood for energy provision is likely to impact negatively on the pulp and paper and wood processing sectors, short rotation coppice plantations are worthy of consideration as a means to enhance the wood supply.

The production of wood in plantations over short rotations is an alternative form of agricultural land use with considerable promise for the future. In addition to providing economic benefits for landowners, short rotation coppice brings with it ecological benefits for society as a whole (Liebhard 2007). Sustainably managed short rotation coppice plantations are a source of renewable energy with very low net carbon dioxide emissions and low levels of nitrogen and sulphur pollutants (Patterson et al. 1994; Matthews and Robertson 2001; Börjesson 2006; BMELV 2007; Bemmann and Große 2011). The reasons for this are that these plantations are a much less management intensive crop than many other plants cultivated for bioenergy and because the root systems, stools and leaves are not removed from the site during the infrequent harvesting operations, so that the impact on soils is also less. Short rotation coppice plantations require a lower chemical input – fertilisers, herbicides and pesticides – than conventional arable crops, and they can serve to increase landscape structure and biodiversity.

There are currently very few areas across the globe where short rotation coppice is practiced to any degree, with two notable exceptions being Brazil and Sweden. As yet, it remains in many ways more a political wish than a land use reality. However, while still a marginal land use, the area of short rotation coppice has expanded steadily over the last decade or two, but to what extent is uncertain. Given that the area is increasing from year to year, the figures quoted in individual studies are often dated. Obtaining clear figures from the literature is also complicated by the aforementioned lack of clarity in the use of alternative terms such as short rotation crops. Moreover, as a relatively new form of land use, short rotation coppice plantations are not separately recorded in most national statistics. On the basis of the data available, Don et al. (2011) estimated a total of somewhere in excess of 30,000 ha short rotation coppice in Europe. For the USA, Wright (2006) calculated an area of short rotation woody crops of around 500 km^2, used for both fuel and fibre, compared to 30,000 km^2 of *Eucalyptus* plantations in Brazil grown solely for woodfuel and between 70,000 and 100,000 km^2 in China. Just what proportion of these woody crops is managed as coppice is not known, however.

In spite of the relatively small area of short rotation coppice cultivated in Europe, the European Union and many of its individual member states rate short rotation coppice highly as a means of biomass production for the purposes of energy generation globally. Indeed, many view short rotation coppice as a welcome alternative to the maize, oilseed rape and other annual energy crops increasingly consuming the arable land area. This latter development is controversial from ecological, nature conservation and landscape protection perspectives. It is also highly questionable in terms of energy and land use efficiency. Short rotation coppice is characterised by numerous advantages over these more traditional energy crops (e.g., Makeschin 1994; Rowe et al. 2010; Glaser and Schmidt 2010), and also by considerably better rates of energy efficiency (Börjesson 2006; Styles and Jones 2007; Bemmann and Große 2011).

For the decision makers at the grass root level, namely farmers, however, there are not only benefits associated with short rotation coppice but also a number of drawbacks and too many uncertainties (Skodawessely and Pretzsch 2009). In the following a general overview of some of the species used for coppice and their characteristics is given, as well as a discussion of the benefits and impediments, and the uses of the wood produced.

4.4.1 Characteristics of Typical Short Rotation Coppice Species

The primary objective of short rotation coppice is the maximisation of wood yield over short rotations. In order to achieve this, the tree species and clones used in short rotation coppice plantations must be characterised by certain traits, whereas other characteristics often valued in tree species used in forestry are irrelevant. Some of the following traits will be of greater or lesser importance in certain parts of the world, but the trees used in short rotation coppice are generally (Liebhard 2007; Schildbach et al. 2009):

- Light demanding species;
- Highly tolerant of both late and early frosts (temperate zones);
- Readily produced in large quantities (e.g., by means of vegetative propagation);
- Relatively easy to establish and characterised by high survival rates;
- Capable of rapid early growth and high biomass increment;
- Able to withstand high levels of competition in closely spaced stands;
- Characterised by high assimilation rates;
- Species with a long vegetation period and characterised by late leaf-fall (tolerant of variable day lengths);
- In possession of a high capacity to coppice or re-sprout from the harvested stool;
- Highly stable;

- Characterised by a small, compact crown with an acute branch angle;
- Not very susceptible to disease;
- Highly tolerant of pests and not prone to browsing; and
- Producers of wood with good thermal characteristics (high calorific value).

Depending on the management objectives and the site, certain other characteristics may also be desirable in short rotation coppice species. In the case of plantations established to grow wood for material use, straight stems may be important. On certain sites species tolerant of either drought or waterlogging may be necessary (Schildbach et al. 2009).

Few of the species potentially used for the purposes of short rotation coppice worldwide have been the subject of breeding programmes to date. Where breeding work has been carried out and different clones and varieties are available, it is important growers choose a variety that is adapted to both the site and the production aims as the differences in biomass production and even survival between the varieties can be considerable.

Box 4.2 Biohof Böhme: A Largely Self-Sufficient Organic Farm Practising Short Rotation Coppice in Eastern Germany

The Böhmes established their first 20 ha of short rotation coppice on their farm in Obercarsdorf, Germany, in 2005. In the years since they have planted another 20 ha. The large yields achieved by the willows and poplars grown on the farm are such – approximately 10 bdt/ha/a – that for every hectare cultivated enough wood chips are produced each year to replace approximately 5,000 l of domestic heating oil. Established for a period of between 25 and 30 years, after which a new tree crop will be planted or the plots restored to conventional agricultural use, the plantations are harvested every 3–5 years, depending on the species and productivity of the individual lots. A 75 kW wood chip heating system uses between 102 and 150 bulk m^3 of the wood chips (17–21 bdt) produced to heat the farm facilities and an adjacent building containing five apartments annually. The heated area amounts to approximately 550 m^2.

As a certified organic farm, no pesticides or herbicides are used on the Böhmes' land. To remove competition from weeds, which can threaten the successful establishment of a crop, the poplar plantations are weeded using Shropshire sheep. The trampling effect of the sheep has the added effect of keeping mice and voles out of the plantation.

The Böhmes were one of the first in their region to participate in short rotation coppice. As a result of this early involvement they are now in a position to market their services as consultants providing advice on the establishment of short rotation coppice and as contractors providing planting services. In addition to using the wood to meet their own heating needs, the Böhmes also produce planting material sold on the regional market. Open to

(continued)

Box 4.2 (continued)

innovation and experimentation, the Böhmes work closely with scientists and engineers from a nearby university in the development of new planting and harvesting equipment and approaches for the tending of plantations. As a result, the enterprise has earned itself a reputation throughout Germany as a pioneer and innovator, and is a model that other enterprises look to for inspiration.

4.4.2 Species Used for Short Rotation Coppice

The principal tree species used in short rotation crops worldwide are few in number, and are limited mainly to eucalypts, poplars, willows, *Robinia* and *Acacia* (Verwijst 2003). Locally other woody species may also be important (refer, for example, to work by Pereira and Pereira 1994; Dalianis et al. 1996; Shackleton 2001; Sims et al. 2001; Rédei 2003; Fang et al. 2004, 2011; Geyer 2006; Buchholz and Volk 2007; Noh et al. 2007; Seebauer 2008; Avohou et al. 2011). The main species used for short rotation coppice in Europe are poplar and willow, and within Europe there are regional differences. Further to the east and south east, as water availability becomes critical, *Robinia* or black locust becomes more prevalent. Short rotation coppice plantations in North America are based primarily on poplar, whereas in Brazil eucalypts predominate. Eucalypts are also commonly used in short rotation coppice in Australia and New Zealand and have considerable potential for plantations in Africa.

4.4.3 Uses of Wood Produced in Short Rotation Coppice

The wood produced from traditional coppice stands and from short rotation coppice plantations can be put to a number of uses. The primary use of wood from modern short rotation coppice, however, is for energy, more particularly for the provision of heat. The generation of electricity from wood is also possible through processes such as gasification and biomass to liquid (BTL), but these are complex and not yet fully developed (see Box 4.3). Heat generation on the other hand represents a simpler and more efficient use of the resource and requires considerably less investment in technology. Wood can be used as the sole raw material or in combination with other fuels.

In many parts of the world, wood-derived fuel still accounts for up to 50 % of the total energy consumed, predominantly in the form of simple woodfuel and charcoal applications (Abell 2005). Indeed, woodfuels account for a greater proportion of energy consumption than all other forms of renewable energy combined (FAO 2010). The advantages of wood produced for fuel in short rotation coppice over other crops such as Jatropha, for example, is that there is no need for a complex refining process in order to produce the fuel. The wood is simply converted to billets or chips and dried. The cultivation and use of the wood can occur locally, with transport over long distances for processing or to reach markets not necessary. Nevertheless, opportunities for export do exist. Certain large global energy providers are currently engaged in transporting woodchips from both Africa and Asia to fuel large power plants in Europe.

Grown under certain conditions, and using appropriate species, the wood produced in short rotation coppice can also be put to material use; for example, in the pulp and paper industry. There is also a growing market for the co-products of short rotation coppice, such as in the oil mallee industry in Australia, where either activated charcoal and leaf oils may be produced. In Brazil charcoal is also produced from eucalypts (Verwijst 2003). Poplar bark may also prove a useful material for use in tanning, whereas the salicylic acid in the bark of willow may have medicinal applications. The wood from short rotation coppice is also being used for gardening purposes in some countries.

Box 4.3 Using Wood to Provide Heat and Electricity

When carefully controlled to ensure complete combustion, modern woodfuel burning systems can be used to provide energy very efficiently and cleanly using automatic, highly efficient boilers and power installations. Approximately 80 % of the energy produced in the burning of wood is released by the combustion of gases formed during heating. The remaining 20 % is produced from the charcoal. Air introduced to the woodfuel aids efficient burning of the gases. Domestic open fires burn at temperatures of between 200°C and 500°C; at around 35 % efficiency. Efficiency is greatly improved in stoves and boilers, up to in excess of 90 %. Introducing hot secondary air above the fuel increases the efficiency of the burn and the gases produced burn at 600–700°C.

Essentially there are three means of converting woodfuel to energy; pyrolysis, gasification and combustion:

Pyrolysis: Pyrolysis involves the heating of wood in the complete absence of oxygen, during which the wood degrades to produce gases, liquids and charcoal. The principle product of the process is a liquid that can be used as a fuel to power a generator. A distinction is made between two forms of pyrolysis: slow pyrolysis and fast or flash pyrolysis. Slow pyrolysis has been used for years to produce charcoal as a solid, stable fuel for industrial and domestic use. Flash pyrolysis, alternatively, is the thermal conversion of biomass at high temperatures over a short time, with reaction times of only a few seconds or less. The aim is to produce gases and liquids for use as biofuel. The gas produced in the fast pyrolysis of wood can be fed back in and burnt to further drive the process. The resulting charcoal can also be

(continued)

Box 4.3 (continued)

burnt. Fast pyrolysis is a relatively new technology, however, and has not been applied in the burning of wood on a commercial scale as yet. As the liquid fuel produced in fast pyrolysis can be stored and readily transported there is considerable interest in further developing the technology. A further form of 'mild' pyrolysis is torrefaction, which is currently also being investigated as a means to improve the transport-worthiness of woody biomass.

Gasification: Combustible gases are given off when the supply of air is restricted as wood is heated. These gases can be cleaned and used to drive an engine, which is in turn used to generate electricity. Gasification is generally more efficient than combustion, especially when generating electricity. The application of the technology to produce electricity from wood is still in the early stages and developments are ongoing. Nevertheless, gasifiers produced by a small number of manufacturers are already available on the market.

Combustion: During combustion wood is completely oxidised. The resulting hot gases are used to produce steam, which drives a steam turbine in order to produce electricity. This is a less efficient means of converting woodfuel to electricity but, unlike pyrolysis and gasification, the technology is well established and the capital costs are relatively low. Almost all woodfuel-powered electricity plants are based on combustion. By using the heat produced by the combustion process as part of a combined heat and power (CHP) scheme, improvements in both efficiency and costs can be achieved.

Source: Ireland et al. (2004, 2006)

4.4.4 Benefits, Drawbacks and Impediments to Short Rotation Coppice

As with so many forms of land use, the pros and cons of short rotation coppice are not absolute and are a function of the site and the land use they replace (Cossalter and Pye-Smith 2003; Elliot 2003; Bielefeldt et al. 2008). Where short rotation coppice replaces a portion of a large scale, intensively managed maize crop situated in an open, poorly structured landscape the plantation will serve to increase biodiversity, for example, and provide benefits in terms of soil and wind erosion. If a coppice plantation replaces natural forest, however, the impact in terms of biodiversity and erosion will be negative. Just some of the benefits will be summarised in the following before the factors currently mitigating against the expansion of short rotation coppice are outlined.

4.4.4.1 Benefits

There is a range of benefits associated with short rotation coppice. Importantly, these plantations represent a means to increase the *wood supply* on the market in the short term. The growing demand globally for wood for energy purposes is leading to conflict between those seeking to use wood for material purposes and those requiring wood for energy. The growing demand for wood is placing a greater strain on the Earth's forests, in tropical, boreal and temperate zones, thereby posing a threat to their sustainable management. Even in countries where the concept of sustainable forest management is well established and widely implemented, the pressure to make greater use of forest residues normally left in the stand after harvesting, so that nutrients may be returned to the soil, is increasing.

The advantages of short rotation coppice plantations extend beyond simply relieving the wood market, however. These plantations also provide ecological advantages relative to many traditional annual cultures. As they are not harvested every year and as the roots remain in the ground for many years the pressure on the *soil* is greatly reduced. This is beneficial in terms of soil erosion but also in that the loss of nutrients from the soil is lessened. Plantations have also been found to positively influence soil structure (Kahle et al. 2005; Lamersdorf et al. 2010).

Short rotation coppice plantations are also characterised by greater *biodiversity* than many traditional agricultural crops (Gustafsson 1987; Berg 2002; Weih et al. 2003; Weih 2009; Glaser and Schmidt 2010; Schmidt and Gerold 2010), provide a better habitat and also represent an additional *structure*-giving element in the landscape (Skärbäck and Becht 2005; Rode 2005). Also of considerable importance in terms of ameliorating climate change is the fact that short rotation coppice is a largely *carbon neutral* form of land use because the carbon released upon burning is carbon that was removed from the atmosphere during the standing time of the plantation (BMELV 2007; Styles and Jones 2007; FAO 2010), with carbon bound for varying lengths of time in the wood of the roots, stools, stems and in the humus remaining on site. The low management intensity and the very limited need for fertiliser application mean that the energy inputs required for cultivation are less than for other, annual biofuel crops. Additionally, there is some evidence to suggest that such plantations can play a role in the *phytoremediation* of contaminated soils and in the treatment of wastes (Aronsson and Perttu 2001; Guo et al. 2002; Klang-Westin and Eriksson 2003; Dimitriou and Aronsson 2005; Cavanagh et al. 2011). Short rotation coppice is also being investigated as a means to recultivate sites previously used for surface mining (Grünewald 2005; Rockwood et al. 2006).

Short rotation coppice plantations also provide *management and economic advantages* for landowners. In many parts of the world the price of wood chips is increasing gradually, and is generally more stable than the values of other agricultural crops. Plantations represent a means to diversify production profiles and provide landowners with a buffer against negative market developments for certain produce, or against crop failures caused by weather extremes or pest outbreaks. The introduction of plantations also represents a means for farmers to adapt their production to possible changes to the local climate generally. In temperate regions of the world, the harvesting of plantations occurs in winter, a season that is otherwise relatively quiet for arable farmers, so providing for a better distribution of labour over the entire year.

4.4.4.2 Drawbacks and Impediments

In spite of the many advantages of short rotation coppice and the strategic importance often attributed to this form of land use at scientific and policy level, in many parts of the world the steps necessary to encourage a more widespread implementation of the practice are not being made. As yet there are very few countries or regions with an unambiguous and definitive stance with regard to short rotation coppice at the policy level. Whereas in some cases general targets have been set in terms of land area or wood volume, no clear indication has been given as to how these goals are to be met and few concrete measures have been taken to remove the obstacles to the establishment of woodfuel plantations. This is also reflected in a general lack of, or the often contradictory nature of the information regarding short rotation coppice available at the level of various national, regional and local agricultural advisory bodies and services. As a consequence, many landowners lack the necessary knowledge in relation to the management and the perspectives offered by short rotation coppice (Weih 2009; Bemmann et al. 2010), and also regarding the marketing of wood chips.

The *high capital investment* relative to traditional agricultural crops required in the establishment of short rotation coppice means that a plantation must remain in place for a considerable period of time. How long will vary depending on local economic and environmental factors. In regions where the costs of land and labour are high, a plantation lifetime of 20–30 years with harvests every 3–6 years is necessary. Where natural productivity is higher and labour costs are lower, the investment and plantation lifetime will decline correspondingly. The consequence of this long term binding of the site is a reduction of the landowners' *flexibility* to react to positive market developments for other crops. Accustomed to an annual income for their produce, a return only every 3–5 years is also a hindrance for many landowners.

Farmers' *knowledge* with regard to the establishment, management, harvesting and marketing of short rotation coppice plantations and their produce is still very limited. Whereas traditional agricultural crops have been the subject of breeding programmes, and developments in the corresponding technology, marketing structures and advisory services have evolved over time, this is not yet the case for short rotation coppice. The knowledge required by the landowner relates, among other things, to the choice of tree species and site, site preparation, the selection of varieties and clones, the possible diseases and pests, growth rates, the calculation of returns, harvesting and marketing of wood chips.

Wood chips are a relatively new product and as such in many parts of the world the corresponding market is only just developing. As a result there is no reliable *market price*, which is a cause of concern for both potential producers and consumers of wood chips and a disincentive to participate in short rotation coppice. Three basic marketing approaches exist for farmers, namely private use, sale to local or regional consumers (community facilities, local industry) and sale to large-scale, supraregional consumers (combined heat and power plants) (Bemmann et al. 2010).

The *equipment and technology* used in the establishment and harvesting of short rotation coppice plantations is often machinery that farmers do not use in the cultivation of traditional crops and so do not have ready access to. This includes planting machines, harvesters, chippers and wood chip drying solutions. As short rotation coppice is still a relatively new form of land use, and as yet not very widely practiced, the corresponding technology is in some cases not yet very advanced (Bemmann et al. 2010).

Another more fundamental issue in many parts of the world is farmers' (lack of) *acceptance* of trees on agricultural land. Where the clearance of trees has been associated with progress, the decision to restore trees to hard-earned agricultural land is not one that is made lightly.

In spite of the scope for environmental benefits, short rotation coppice can impact negatively on the *environment* where due consideration is not given to the surroundings. Short rotation coppice should not replace natural forest or be established within areas with a high nature conservation value. Where water availability is a problem, the suitability of short rotation coppice plantations must also be carefully considered as they may impact negatively upon the local hydrology. It is essential that a landscape approach be adopted when planning the establishment of a plantation to ensure that there is no adverse impact on ecosystems, biodiversity or on the hydrological cycle. The social context must also be taken into consideration to ensure that plantations benefit local communities rather than work to their detriment (Cossalter and Pye-Smith 2003).

The main features of short rotation coppice are summarised in the SWOT analysis presented in Table 4.4.

4.5 Outlook

4.5.1 The Outlook for Agroforestry

As highlighted by Nair and Garrity (2012), the fact that nearly a billion hectares of agricultural land currently have a tree cover in excess of 10 % demonstrates the global importance of agroforestry. It is now widely recognised as being a viable land use alternative with a key role to play in banishing hunger and poverty, and in rebuilding resilient natural environments. Increasingly, centuries-old traditional agroforestry approaches are being implemented on the basis of a solid scientific foundation.

Table 4.4 SWOT analysis of short rotation coppice plantations

Strengths	Risk is spread as a consequence of the diversification of farm production
	Environmental co-benefits
	Use of land unsuitable for agriculture
	Greater efficiency of wood as an energy crop
Weaknesses	High capital investment relative to other energy crops
	Lack of knowledge relating to species, plantation management and marketing of produce
	Market access often problematic, difficult to aggregate sufficiently high timber volumes
	Lower land productivity than intensive agriculture
Opportunities	Additional income from payments for environmental services (PES), carbon credits
	Increasing demand in many countries for wood
Threats	Insufficient support from agricultural extension services
	Competing demands for land
	Failure to develop local markets for wood chips

Against a background of ongoing deforestation and forest degradation, a growing demand for additional sources of timber, woodfuel and many other tree products is leading to improved prices for farm-grown wood; a development to which more and more land owners are responding. An increase in the extent of tree cover on farms is, therefore, likely to continue (Nair and Garrity 2012).

Especially for many old tropical soils with unfavourable chemical compositions and physical structures, providing shelter and the incorporation of organic matter by means of woody perennials is key to a sustainable production of crops and fodder, and to the adaptation of agriculture to climate change. This carbon sequestration and storage also provides a valuable climate mitigation option, which can generate some additional carbon income in agricultural projects, as evidenced, for example, in Kenya (Woelcke and Tennigkeit 2009; Friedman and Shames 2012). At the same time, agroforestry systems conserve biodiversity in agricultural landscapes, protect groundwater and relieve the pressure on the remaining forests.

In some parts of the world the removal of legal and policy constraints previously serving to hinder the development of agroforestry are having positive effects (Minang et al. 2012; Ajayi and Place 2012), while elsewhere economic incentives to land managers are beginning to provide an impetus for agroforestry (Kumar et al. 2012).

4.5.2 *The Outlook for Short Rotation Coppice*

The outlook for the expansion of short rotation coppice globally over the coming years is good but many barriers need to be overcome and uncertainties expunged. The growing demand for wood worldwide and the increasing recognition of the much higher energy efficiency and positive carbon balance associated with short rotation coppice over other energy crops favour this expansion. In various parts of the world studies of the most suitable species and management approaches have been carried out, or are currently underway, and a good basis for coppice systems has been established. Elsewhere, however, there are still considerable knowledge gaps with regard to the appropriate species, cultivation practices, the expected yields, technology and so on. The opportunities for farm diversification and the creation of an additional source of income, as well as the possibility to achieve greater independence from fossil fuels and large energy concerns are just some of the incentives that will potentially motivate small and large landowners to consider participating in short rotation coppice for the purposes of producing wood chips. Production on a scale going beyond mere subsistence use, however, requires the development of markets for this relatively new product. In order to expand, existing and successful wood chip networks beginning with the producer and ending with the consumer, and including all of the various partners in between, need to be highlighted and used as models upon which a wider application can be based.

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